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Time-Limited Visual Resolution in Pilot Trainees

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By

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Time-Limited Visual Resolution in Pilot Trainees

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Superior vision is needed for piloting aircraft in military and civilian environments. Although visual evaluations of potential pilots typically are conducted with no limit on viewing time, aviation and related occupations require superior vision under time-limited viewing conditions, and assessment of this capability is needed. The purpose of this study was to evaluate time-limited visual resolution in pilot trainees. A forced-choice letter recognition task was used to measure visual acuity (VA) and small letter contrast sensitivity (SLCS) in 37 trainees who had satisfied all vision requirements for pilot training. VA and SLCS were highly correlated (r = 0.76), indicating that the two tests measure similar aspects of visual resolution. However, although VA scores were distributed across 0.16 log units (two lines of letters on a VA chart), SLCS scores varied across 0.35 log units, which is nearly four lines on the SLCS chart. The variation in SLCS performance could be explained, in part, by subtle refractive error in pilot trainees. The results exemplify differences in performance among visually qualified trainees, and underscore the need for proper refractive correction. SLCS is a useful screening test for identifying subtle changes in vision that herald the need for optical or medical intervention.

Introduction

Optimal visual acuity (VA) is a requirement for piloting aircraft in the U.S. Army. Warrant officer candidates for flight school must have uncorrected VA of at least 20/20 in each eye, and no significant refractive error (-0.25 D to +1.75 D).[1] Implicit in these requirements is the assumption that most pilots will not require corrective lenses during flight. Spectacle wear can constrain performance when using visual aids such as helmet-mounted displays and night-vision goggles, particularly when combined with chemical protective masks.[2-4] Thus, the ideal candidate for pilot training has 20/20 vision and no obvious need for refractive correction.

But is 20/20 good enough? Most healthy young adults can see better than 20/20. In fact, 20/20 is near the lower limit of normal VA in optically corrected individuals tested under standard conditions of illumination.[5-7] Hence, there is a range of VAs better than 20/20 that encompasses the candidates who satisfy vision requirements for pilot training. This range of vision is of interest since it may be predictive of performance differences in operational environments.

In previous studies, we showed that small letter contrast sensitivity (SLCS) is more sensitive than VA to several factors including defocus (blur),[7] stimulus intensity,[8] and the visual improvement achieved with two eyes compared to one.[9] Moreover, SLCS was found to be more highly correlated than VA with small amounts of refractive error in visually normal pilot trainees.[10] The value of measuring CS to assess pilot performance has been demonstrated in previous studies.[11,12] However, SLCS is unique in its use of small letters to assess CS for recognition of fine detail. Its complements VA by providing a sensitive, adjunctive measure of visual resolution.

Although in previous studies of SLCS, and during clinical assessment of VA, observers were given ample time to recognize letter stimuli, the high speeds of aviation and other operational environments present a rapidly changing visual scene. Pilots and soldiers have limited time to process visual information in order to make critical decisions. It would be useful to assess time-limited visual resolution to determine whether it can better identify individual differences that correlate with operational performance. This paper describes time-limited VA and SLCS in pilot trainees, and how differences in SLCS can be explained, in part, by subtle refractive error, and possibly by differing capabilities that influence pilot performance.

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Methods

The stimuli for time-limited VA and SLCS were single letters generated by computer software and displayed at the center of a VGA monitor. The letters always appeared darker than the uniform, white background, which had a constant luminance of 116 cd/m^2. Letter contrast was controlled by software that reduced the intensity of the monitor guns relative to the white background. A cross-hair consisting of thin, black horizontal and vertical lines always appeared at the center of the screen to guide fixation to where the letter would appear periodically (but not overlapping the letter), and to help maintain the appropriate accommodative response. The entire screen subtended an angle of 3° at a viewing distance of 4.8 m.

Single letters were programmed to appear briefly (0.67 seconds) followed by an interstimulus interval of 1.66 seconds. The next letter then appeared followed by an interstimulus interval, and so on until a total of 50 letters were presented (25 VA, 25 CS), with the order of presentation randomized across VA and CS. The VA letters were of high contrast (93%) and ranged in size from 20/12.6 to 20/31.7 in 0.1 log unit steps (-0.2 to 0.2 log of the minimum angle of resolution [logMAR]).[13] Five letters were presented at each acuity level. The SLCS letters were of constant size (20/25), but ranged in contrast from 5 to 13%, also in 0.1 log steps, with five letters per contrast step.

Testing was conducted in a darkened room with the monitor as the only source of illumination (Fig. 1). The subjects were 37 warrant officer candidates (age 21 to 29, mean = 25.6 ± 2.5 years) who previously passed all visual requirements for flight training including visual acuity, refractive error, heterophoria, and stereopsis. Subjects were tested binocularly without optical correction, since most would fly under those conditions. Each subject initially adapted to the uniform field of the monitor for about 5 minutes, during which instructions were given. Subjects were told that single letters would appear briefly at the center of the screen, and they were to verbally report each letter seen. Subjects were encouraged to give their best guess if unsure. A member of the experimental team recorded responses on a score sheet, assigning 0.02 log units per letter read correctly.[3,5] After completing the first run (50 letters), the subject rested for 2 to 3 minutes and then completed a second run of 50 letters. All subjects gave their informed consent after protocol approval by our institutional review committee. Subjects also were assured that their responses would not be used as any form of discriminator for flight status or future training.

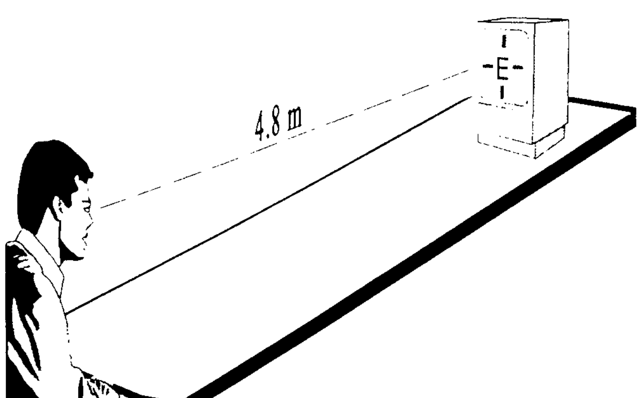

Fig. 1. Diagram of the experimental test conditions. The observer was seated 4.8 m from the computer display on which single letters appeared briefly (0.67 seconds) centered on the screen. The letters were either high in contrast but varied, from trial to trial, in size (visual acuity), or of constant, small size (20/25) but varied in contrast (small letter contrast sensitivity).

Results

Figure 2 shows SLCS (log contrast sensitivity) plotted against VA (logMAR) for 37 flight school candidates. Each data point is the mean of two runs corrected for the variability between runs. Correction for variability in each subject was made by subtracting one-fourth of the difference between runs from the subject's mean score. For example, a subject scoring 1.28 and 1.20 on SLCS would have a mean of 1.24, but a corrected score of 1.24 - (0.8 ÷ 4) = 1.22. Yet a subject who scored 1.24 on both runs would receive the mean score of 1.24. This slight correction was used to distinguish between different levels of consistency in performance, and, as discussed subsequently, proved to be more highly correlated with subtle refractive error.

The data in Figure 2 are displayed on log scales that span equivalent ranges (0.6 log units), which facilitate direct comparison of VA and SLCS in pilot trainees. As shown in Figure 2, VA and SLCS are highly correlated (r = 0.76), indicating that the two tests measure similar aspects of visual resolution. However, although performance varies across 0.16 log units of VA, it is distributed across 0.36 log units of SLCS, a 60% greater range. The

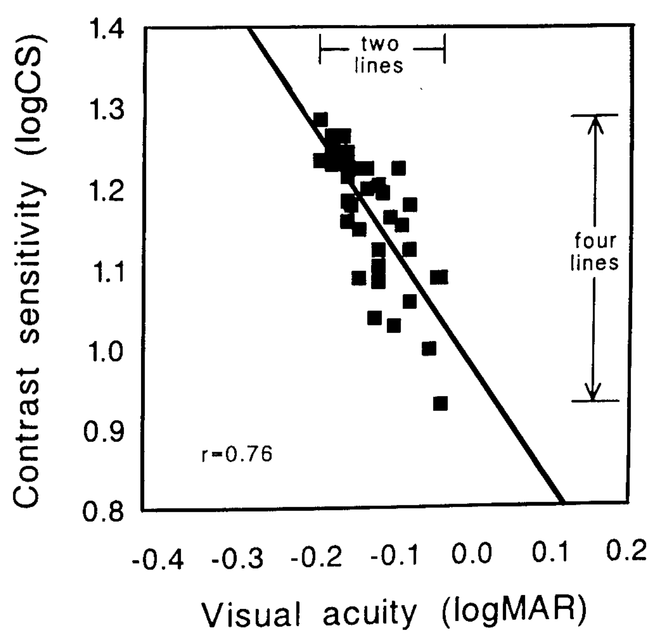

Fig. 2. Small letter contrast sensitivity is plotted against visual acuity for 37 pilot trainees. Contrast sensitivity is the log of the inverse contrast threshold (logCS), and visual acuity is the log of the minimum angle of resolution (logMAR). Although logCS and logMAR are highly correlated (r = 0.76), scores are distributed across a more extensive range in the contrast dimension, indicating that it offers a more sensitive index of visual function. Expressed as lines of letters on a standard vision chart, scores are distributed across two lines of visual acuity, but across four lines of contrast sensitivity.

variation in VA represents only two lines of letters on a standard clinical acuity chart, whereas the variation in SLCS represents nearly four lines on the SLCS chart of similar design.[7,10]

The greater distribution of SLCS than VA could reflect response variability unrelated to actual differences in performance. Alternatively, the larger spread of SLCS scores may indicate that SLCS is a more discriminating index of visual differences produced by small amounts of refractive error.[10] To explore this issue, SLCS and VA were evaluated as a function of (cycloplegic) refractive error determined during previous flight physical examination. Since VA and SLCS were evaluated binocularly and refractive data were available for both eyes, refractive error was referenced to the most myopic meridian, which typically was the more myopic of the subject's two eyes. This was done because small amounts of myopia would have the most detrimental effect on performance,[10] and preliminary analysis indicated that this approach best explained the variability in scores. Figure 3 shows mean VA (left panel) and SLCS (right panel) plotted against refractive error (lower values of logMAR indicate better VA). Although there is a tendency for VA to decrease with low myopia and higher amounts of hyperopia, this relation is not significant ($F = 3.02$, $p = 0.062$). In contrast, there is a definite peak in SLCS performance at +0.75 to +1.00 D of hyperopia, and this curvilinear relation is significant (second-order polynomial regression: $F = 8.27$, $p < 0.001$). Although refractive error explained 33% of the variability in SLCS ($r^2 = 0.33$), it accounted for only 15% of the variability in VA ($r^2 = 0.15$).

In a previous study of pilot trainees tested with unlimited viewing time, SLCS also was more highly correlated than VA with small amounts of refractive error.[10] The present results extend this finding to include a larger range of refractive error and time-limited viewing conditions. Nevertheless, despite the clear correlation between SLCS and refractive error, a substantial degree of variability in performance remains unexplained. Further research is needed to determine whether this additional variability in SLCS is predictive of differences in performance in operational environments.

Discussion

This study demonstrates that small letter contrast sensitivity provides a sensitive index of time-limited visual resolution in pilot trainees. The results are in agreement with previous studies that demonstrated the sensitivity of SLCS to defocus,[7] luminance,[8] binocular visual enhancement,[9] and subtle refractive error in pilot trainees.[10] Whereas in previous studies SLCS was tested with unlimited viewing time, the present results underscore the sensitivity of this approach under time-limited viewing conditions similar to what may be encountered in an operational environment.

Although VA was not strongly correlated with refractive error in the subjects tested, SLCS peaked at low hyperopia (+0.75 to +1.0 D), but declined with greater or lesser amounts of hyperopia, particularly as values approached myopia. This finding ostensibly is unclear, since subjects were uncorrected during testing, and it may be expected that best performance would occur at emmetropia (zero diopters). However, as during initial qualification for pilot status, refractive error was based on cycloplegic measurement in which accommodation (focusing ability) was neutralized pharmacologically. This eliminated any excess accommodation due to tonic factors or observer tendencies that would operate under normal viewing conditions. The consequence of neutralizing this excess accommodation is to shift refractive error toward hyperopia. Hence, a tendency to accommodate under normal (noncycloplegic) conditions in a subject with low hyperopia would optimize visual performance on SLCS, since the accommodation

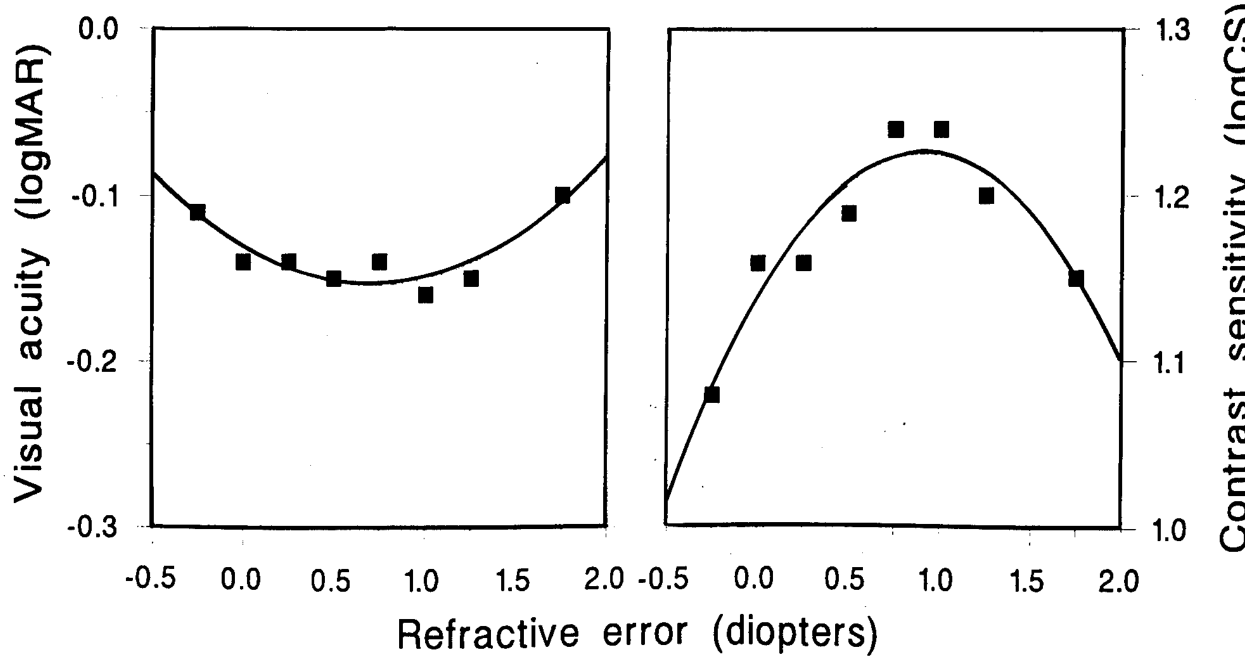

Fig. 3. Mean visual acuity (logMAR) and small letter contrast sensitivity (logCS) are plotted against refractive error (lower logMAR values indicate better visual acuity). Both visual acuity and contrast sensitivity show a curvilinear relation to refractive error with peak performance between 0.75 and 1 D of hyperopia, but this relation is more prominent for contrast sensitivity.

would compensate for the refractive error. However, the emmetrope or very low myope who accommodates more than the stimulus demand would suffer a reduction in visual resolution. Although, based on cycloplegic exam, this may encourage us to select low hyperopes for flight training, a substantial degree of variability in performance remains unexplained by refractive error. Additional testing would be needed to substantiate this concept, such as measurement of the accommodative response under normal viewing conditions. The present results do indicate the importance of correcting subtle refractive error, particularly when myopic in nature. Perhaps SLCS could be implemented as a screening procedure to indicate when refractive error has changed sufficiently to warrant optical correction (Dr. Dudley Price, personal communication).

As in previous studies,[7-10] the present findings underscore the greater sensitivity of SLCS than VA to factors that affect visual resolution. This is due to the precipitous, descending slope of the contrast sensitivity function (CSF). The CSF, which relates contrast sensitivity to spatial dimension, is steep near the acuity limit. Therefore, as illustrated in Figure 4, any perturbation, such as defocus, that causes a reduction in VA produces a greater decrease in SLCS. Conditions that can produce small decrements in VA, such as refractive surgery (e.g., radial keratotomy),[14] edema of the cornea or retina (e.g., diabetes),[15] optic neuritis (e.g., multiple sclerosis),[16] and visual loss in the aging eye (e.g., cataracts),[17] produce larger reductions in SLCS.[18] As demonstrated in the present study, SLCS also provides a more discriminating approach for identifying candidates for occupations requiring unique visual abilities, such as those in space and aviation. Currently we are developing a hard copy, letter chart version (called the Small Letter Contrast Test; Fig. 5) for widespread use in clinical, research, and institutional settings.[18]

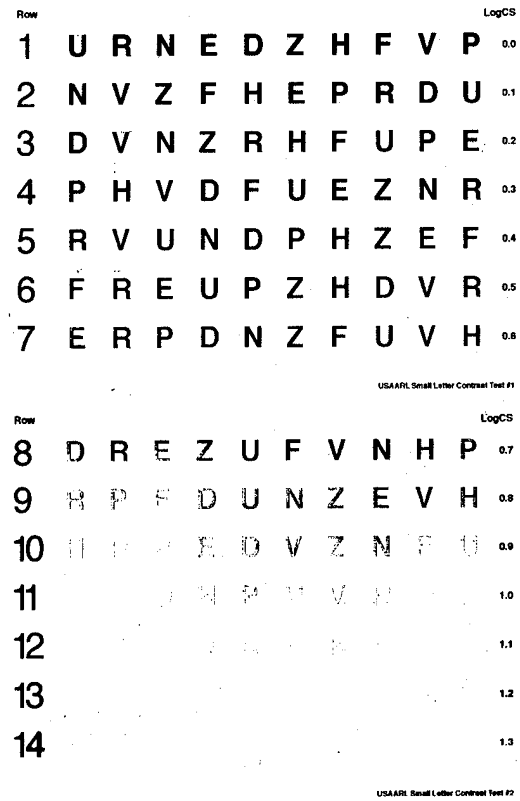

Fig. 5. The newly developed Small Letter Contrast Test (SLCT), a letter chart test for general use. The SLCT has 14 lines of letters with 10 letters per line. Contrast varies by line in 0.1 log steps and credit is given for each letter read correctly (0.01 log unit per letter). Letter size is 20/25. The present study used single letters displayed on a computer monitor in time-limited fashion.

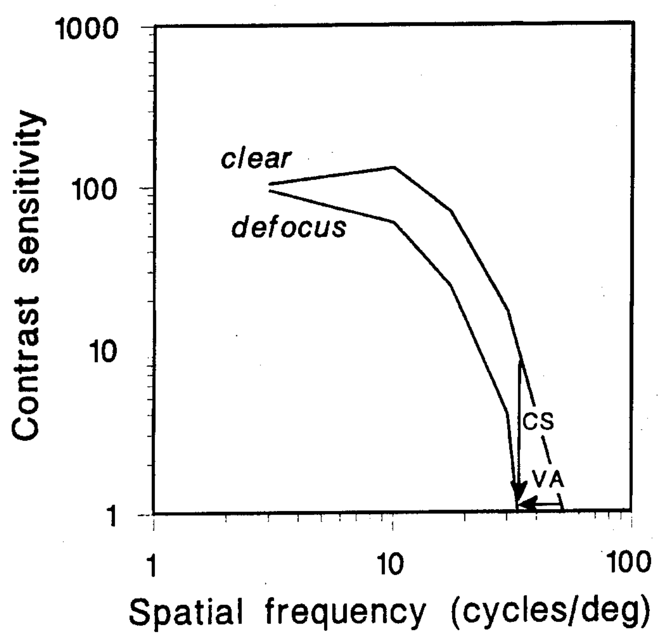

Fig. 4. The contrast sensitivity (CS) function that relates CS (inverse contrast threshold) to spatial detail (spatial frequency in cycles per degree of visual angle). The effect of defocus on the CS function is shown diagrammatically. Due to the steep descending slope of the CS function, a decrease on the *x* axis, which represents the loss of visual acuity (VA), is associated with a relatively larger decrease on the *y* axis, which represents the loss of CS.

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